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SUMMARY OF RESEARCH

1.0 Threshold Switching in Thin-Film Devices

1.1 Noise Measurements on Threshold Switches

Personnel: B.P. Mathur, F.O. Arntz

A program has been initiated to study the noise spectrum of thin-film threshold switches. The fluctuations in voltage across a device connected to a current source has been measured and frequency analyzed. It was determined that the power density spectrum has a $1/f^2$ dependence on frequency. As the threshold point is approached, the noise grows and some pulses appear. Attempts are being made to characterize these pulses. The noise studies are being repeated on devices with smaller cross-sectional areas and different thicknesses. It is hoped that these experiments will lead to an understanding of the observed fluctuations in device threshold voltage and of the dynamics of free carriers in amorphous semiconductors.

1.2 Photoconductivity and Photovoltaic Measurements

Personnel: D.K. Reinhard, F.O. Arntz

Amorphous-semiconductor devices have been manufactured with both ohmic (Mo and Al) and non-ohmic (p- and n-type Si) contacts. The current-voltage characteristics of such devices have been studies and are strikingly different. Non-ohmic contacts do not produce symmetric characteristics, and rectifying behavior is obtained for p-type Si contacts. The results suggest a band model in which amorphous semiconductor p-type Si interfaces exhibit significant band-bending, but the interfaces between amorphous semiconductors and n-type Si result in essentially flat bands.

Devices with transparent aluminum contacts are being investigated with regard to photovoltaic and photoconductivity effects. Thus far, the studies have been restricted to 50μ-3mm thick threshold switches of composition $Te_{40}As_{35}Si_{15}Ge_{7}P_{3}$. Results have been consistent with the band model described previously.

1.3 Temperature Studies of Threshold Switching

Personnel: L.P. Flora, G.W. Lake, D. Adler

Low temperature studies of thin-film threshold switches have been carried out down to 4°K. No qualitative differences have been found in switching characteristics, even at liquid He temperatures. This is in disagreement with electronic models for switching which depend on double injection through narrow Schottky barriers, since these barriers should be frozen in for at least months at 4°K. However, turn-off and reswitching occurred in the normal manner at these temperatures. The non-ohmic pre-threshold effects at low temperatures appear to follow a power law rather than an exponential in most cases.

A program has been initiated to study the effects of annealing at high temperatures on the electrical conductivity and switching parameters. The object is to correlate the decrease of threshold voltage with changes in the active material resulting from annealing effects. This could determine the temperature attained at the center of the filament during switching and perhaps even determine whether switching is primarily thermal or primarily electronic in nature.

1.4 Electrothermal Mechanisms for Switching

Personnel: T. Kaplan, D. Adler

The program in which several electrothermal models for thin-film switching have been developed and quantitatively calculated is nearing completion. It has been shown that a pure thermal model with negligible electrode heating cannot lead to negative resistance, but significant heating, as could occur if the electrodes were thick can produce switching characteristics. Alternatively, non-ohmic electronic effects easily produce switching from Joule heating, in agreement with experimental measurements on chalcogenide glasses.

The equations developed have been applied to a case in which the temperature dependence of both electrical and thermal conductivity has been measured on a material that exhibits threshold-type behavior, Si-doped YIG. This enabled us to predict threshold voltage and threshold current essentially from first principles. Excellent agreement between experimental and theoretical I-V characteristics was obtained for devices of several different thicknesses.

2.0 Crystalline and Amorphous Silicon-Tellurium Alloys

Personnel: K.E. Petersen, D. Adler

Physical properties of single crystals of Si_2Te_3 and amorphous films in the Si-Te system have been measured. The single crystals, 50-1000 μm thick, were grown by vacuum sublimation. Optical absorption experiments indicate that the band gap is 2.2 eV at 300°K, and increases with decreasing temperature by 1 meV /°K. A broad photoluminescence peak appears near 1.3 eV, and can be associated with a particular kind of defect. Thin films, 200 Å - 2 μm thick, of both crystalline and amorphous Si_2Te_3 have also been prepared, as well as amorphous films of other compositions in the Si-Te system. The amorphous films have absorption edges which fall along a smooth

curve between those of crystalline Te and crystalline Si_2Te_3, indicating at most small changes in gap with positional disorder. The electrical resistivity behavior also indicates only slight differences between crystalline and amorphous films of similar compositions. The extrapolated value of high-temperature resistivity is essentially the same for amorphous as for crystalline films; the difference in resistivity at finite temperatures is due primarily to the variation of activation energy with composition. DTA and X-ray measurements on amorphous films indicate a phase separation occurs at elevated temperatures, resulting in a crystallization of Te. The small (0.3 eV) gap for Te dominates the optical absorption of crystallized films. This suggests the possible application of Si-Te films for bulk optical memory devices. Infrared measurements on $Si_{20}Te_{80}$ indicate the presence of Si-Te and Te-Te bonds in this glass-forming material. The major differences between crystalline and amorphous films are the lack of well-defined structural defects in the latter and also the lack of a large density of dangling bonds as evidenced by EPR measurements. These results are consistent with the random covalent model for the structure of amorphous solids. All of these measurements have been used to propose band models for both the crystalline and amorphous materials.

3.0 Theoretical Studies of Amorphous Semiconductors

3.1 Percolation Studies in Three Dimensions

Personnel: L.P. Flora, S.D. Senturia, D. Adler

A program has been initiated to determine the electrical conductivity as a function of fractional occupancy for percolation along a three-dimensional simple cubic lattice. This result is important for theoretical

models for amorphous semiconductors, especially for estimating the sharpness of the mobility edges between localized and extended states in the bands of disordered solids. Preliminary results indicate the transition in conductivity is quite smooth, suggesting a gradual mobility increase rather than a sharp edge. Final results will shortly be available.

3.2 Optical Edges in Amorphous Semiconductors

Personnel: D. Adler

A covalent model for the absorption edge in amorphous semiconductors indicates that the band tail states are optically active, even some localized-localized transitions. The sharpness of the observed absorption edge can be due to one of two different effects; for highly disordered solids, the effects of electronic correlations in localized states can lead to a sharp edge near half the intrinisic mobility gap, while for elemental disordered materials, the definite value of the maximum allowed bond angle distortion produces a well-defined optical gap.

4.0 <u>EPR Measurements on Amorphous Solids</u>

Personnel: C. Schlenker, D. Adler, S.D. Senturia

Measurements of the spin density on several corresponding crystalline and amorphous materials are being carried out as a function of temperature from 4-300°K. Preliminary results show that the EPR signal in amorphous solids cannot be detected at room temperature, but becomes observable at very low temperatures, as might be expected if the relaxation time is very short above 77°K. Thus failure to observe EPR signals at 300°K does not necessarily imply the lack of dangling bonds, and measurements at 4°K are essential.

PUBLICATIONS

1. D. Adler, "Amorphous Semiconductors," Critical Reviews in Solid State Sciences 2, 317 (1971).

2. T. Kaplan and D. Adler, "Thermal Effects in Amorphous-Semiconductor Switching," Appl. Phys. Letters 19, 418 (1971).

3. D. Adler and J. Feinleib, "Localized States in Narrow-Band and Amorphous Semiconductors," Electronic Density of States, L.H. Bennett, ed., N.B.S. Special Publication 323, Washington, D.C., 1971, pp. 493-504.

4. D. Adler, "Metal-Insulator Phase Transitions: Science and Technology," Dynamical Aspects of Critical Phenomena, J.I. Budnick and M.P. Kawatra, eds., Gordon and Breach, N.Y., 1972, pp. 392-430.

5. T. Kaplan and D. Adler, "Electrothermal Switching in Amorphous Semiconductors," J. Non-Cryst. Solids 8/9, 538 (1972).

6. D. Adler, H.K. Bowen, L.P.C. Ferrao, D.D. Marchant, R.N. Singh, and J.A. Sauvage, "Effects of Thermal-Neutron Irradiation on Amorphous-Silicon Films," J. Non-Cryst. Solids 8/9, in press.

7. J.A. Sauvage, C.J. Mogab, and D. Adler, "Temperature-Dependent Tunnelling into Amorphous Silicon," Phil. Mag., in press.

8. D. Adler, "Electrical Conductivity in Ceramics," Bull. Am. Ceram. Soc., in press.

9. T. Kaplan, D.C. Bullock, D. Adler, and D.J. Epstein, "Thermally Induced Negative Resistance in Si-Doped YIG," Appl. Phys. Lett., in press.

10. B.P. Mathur and F.O. Arntz, "Strain-Sensitive Properties of Threshold-Switch Devices," J. Non-Cryst. Solids 8/9, in press.

11. D. Adler and S.C. Moss, "Amorphous Memory Devices and Bistable Switches," J. Vacuum Sci. Tech., to be published.

PAPERS PRESENTED AT MEETINGS

1. D. Adler, "Amorphous Semiconductors," Series of three invited lectures at the Franco-Russian Summer School on Phase Transitions in Semiconductors, Montpellier, France, July, 1971.

2. T. Kaplan and D. Adler, "A Thermal Model for Threshold Switching in Amorphous Semiconductors," contributed paper at the International Conference on Amorphous and Liquid Semiconductors, Ann Arbor, Mich., Aug., 1971.

3. B.P. Mathur and F.O. Arntz, "Strain-Sensitive Properties of Threshold-Switch Devices, contributed paper at the International Conference on Amorphous and Liquid Semiconductors, Ann Arbor, Mich., Aug., 1971.

4. D. Adler, H.K. Bowen, L.P.C. Ferrao, D.D. Marchant, R.N. Singh, and J.A. Sauvage, "Effects of Thermal-Neutron Irradiation on Amorphous-Silicon Films," contributed paper at the International Conference on Amorphous and Liquid Semiconductors, Ann Arbor, Mich., Aug., 1971.

5. K.E. Petersen, V. Birkholz, and D. Adler, "Properties of Crystalline and Amorphous Silicon Telluride," contributed paper at the American Physical Society Meeting, Atlantic City, N.J., scheduled for Mar., 1972.

6. T. Kaplan, D.C. Bullock, D. Adler, and D.J. Epstein, "Threshold Switching in Si-Doped YIG," contributed paper at the American Physical Society Meeting, Atlantic City, N.J., scheduled for Mar., 1972.

7. D. Adler, "Electronic Phase Transitions," invited paper at the Conference on the Local Structural Order and Deconposition of Ti, U and Zr-base B.C.C. Solid Solutions, Ithaca, N.Y., scheduled for May, 1972.

8. D. Adler, "Amorphous Memory Devices and Bistable Switches," invited paper at the Princeton Conference on Memory Materials and Devices, Princeton, N.J., scheduled for May, 1972.

9. D. Adler and T. Kaplan, "Non-Equilibrium Insulator-Metal Transitions," invited paper at the Soviet Conference on the Metal-Dielectric Transitions, Moscow, U.S.S.R., scheduled for June, 1972.